THE MAGNETICS

OF

THE NAIRNE PYRITE FORMATION

by W.K. THIELE

University of Adelaide
Department of Economic Geology
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CONTENTS.

The Nairne Pyrite Formation is a sedimentary sulphide deposit occuring near the base of the Kanmantoo series of rocks.

The average sulphide content of the formation is 10%, half of which consists of pyrrhotite.

The measurement of susceptibility and permanent remnant magnetism of the formation, ground magnetic surveys across the horizon, and the analysis of aeromagnetic maps covering the northern area of outcrop are described.

The results obtained are discussed and some conclusions drawn on the applicability of magnetic prospecting to the search for this deposit.

Footnote.

Since the time of writing this report, the name of the Nairne Pyrite Formation has been altered.
The horizon is now known as the Bruckunga Formation.
Unfortunately, it was not possible to alter the text, and the reader is asked to read, "Bruckunga Formation" for "Nairne Pyrite Formation" where necessary.

Introduction

The purpose of this paper is to describe the work carried out on the magnetic properties of the Nairne Pyrite Formation.

The area considered in this study is on the eastern side of the Mount Lofty Ranges and is shown in Map I. This covers approximately the northern half of the total area along which the pyrite formation outcrops.

The work was intended to show what effect the magnetic properties of the formation had on the anomaly produced by the horizon for both ground magnetic surveys and also total intensity aeromagnetic surveys.

To do this the following techniques were employed.

(1) The determination of the intensity and direction of the permanent remnant magnetism, and the susceptibility, possessed by the pyrrhotite contained in the formation.

(2) Magnetic surveys across the horizon using a vertical-force magnetometer. This was carried out in an area where the attitude of the horizon is known.

(3) An examination of the aeromagnetic maps which cover the area shown in Map I.

As far as can be ascertained by the writer no previous work of this nature has been carried out on the horizon. Mineragraphic studies, mainly to determine the nature and origin of the sulphides have been made by Skinner (1958) and La Ganza (1959).

This work was carried out during 1961 as part of the Honours Geology course.

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Mr. Hammer and the rest of the staff at the Bruchunga Mine were always co-operative, when visits were made to the quarry.

Finally, special thanks are due to Mr. D. Virgo who assisted in the collection of many of the specimens.

GENERAL GEOLOGY.

This description of the geology is taken mainly from Skinner (1958).

The Nairne Pyrite Formation is a series of pyrite and pyrrhotite bearing greywackes and siltstones occuring on the eastern side of the Mount Lofty Ranges. The series of beds in which it occurs is the Kanmantoo Group, a series of at least 26,000 feet of fine grained quartzites, greywackes and siltstones.

The age of the group is uncertain, but is considered to be Cambro-Ordivician.

The Nairne Pyrite Formation has been proposed as the base of this group. However, although the formation forms a convenient marker horizon in an otherwise monotonous sequence, it certainly does not represent a break in sedimentation.

Evidence suggests that the pyrite formation occurs at, or slightly above, a point marking a change in the mode of sedimentation. The beds change from a mixture of coarse and fine grained, quartz rich beds below, to a vast thickness of very fine grained rocks above.

The Kanmantoo Group has been subjected to regional metamorphism, which increases in grade from the south-west towards the north-east. Much of the area of good outcrop lies in the quartz-andalusite - muscovite - plagioclase grade, but in places a quartz - sillimanite - orthoclase -plagioclase grade is reached.

The pyritic beds, which form conspicuous outcrops, have been mapped for a strike length of 65 miles and are certainly more extensive than this. There are two major sulphide-bearing members which vary in thickness from 6 inches to 400 feet, but are generally between 50 feet and 100 feet thick.

Three smaller, more limited members occur stratigraphically above the main units.

Each sulphide-bearing member is made up of many thin-bedded sulphide rich greywackes and siltstones. Individual beds within a member range from 1 inch to 10 feet thick. The sulphides are strung out parallel to the bedding.

The amount of sulphide within a member is remarkably constant along the strike except where the beds pinch out. From bed to bed there is a variation of from 1% to 15% sulphides by volume, but the member as a whole averages about 10%.

The pyritic beds weather rapidly, forming a resistant limonite - quartz - kaolin gossan.

Pyrrhotite disappears rapidly and is not seen at outcrops. Pyrite is more resistant and is often found as residuals enclosed in a limonite-iron sulphate halo.

Sedimentary banding throughout the pyritic horizons is well defined, both macroscopically and microscopically, by differences in composition and grain size.

The pyrite layers are parallel to the bedding and are spaced at intervals of 0.5 cm. to 5 cm., with fine-grained pyrite and pyrrhotite disseminated through the silicates between them. Laterally the pyrite bands die out within a few feet, and are generally no more than a foot long.

Where the beds show no concentration, the sulphides occur as discrete grains uniformly distributed through the silicates.

Within any particular pyritic member, pyrite and pyrrhotite are present in roughly equal amounts, though the proportion of one to another varies widely from bed to bed within the member.

Pyrite predominates in coarse grained beds and pyrrhotite in the very fine grained and highly micaceous beds. Within the concentrated pyrite layers there may also be small crystals of pyrrhotite.

Oxidation and secondary alterations are wide spread but decrease rapidly with depth. However, at the Shepherd Hill quarry, 3 miles north of Nairne these effects have been noticed even on the deepest levels and also in an adit under Shepherd Hill. Below the level of complete oxidation extensive alteration of pyrrhotite to marcasite and in places to pyrite, occurs.

Origin.

The sulphides are thought to have been originally hydrous iron sulphides. These were apparently initially deposited chemically in shallow water and later re-deposited in deep water in the sediments as seen today. Later metamorphism has broken down the original sulphides to give the mineral assemblages observed at the present time.

At the Shepherd Hill quarry the beds thicken locally and are mined for their sulphur content. The strike of the rocks is approximately north-south and the beds dip approximately 70° to the East.

The horizon here is divided into three ore beds (Beds 1, II, and III) and are separated by two waste beds (Beds A and B) which do not contain a sufficient amount of sulphur to be of commercial value.

Mining is carried out by open-cut methods.

Magnetic Measurements.

Measurements were made on samples from the Quarry at Bruckunga to determine the value and direction of any permanent magnetization that the formation might have, and also the susceptibility.

Permanent Remnant Magnetism.

Rocks containing pyrrhotite or magnetite are often permanently magnetized. (This magnetization need not be in the direction of the earth's present magnetic field and, in fact, can be in any direction).

Igneous rocks formed from a molten magma may acquire a magnetization as they cool through the Curie temperature (this is the temperature above which a body loses its magnetism). This thermo-remnant magnetism lies in the direction of the earth's magnetic field as it was at the time of cooling.

When sediments are laid down on the floors of lakes or seas under fairly quiet conditions, small grains of magnetic minerals such as magnetite ($Fe_3 O_4$) or pyrrhotite (Fe S) tend to orientate themselves in the direction of the earth's magnetic field as it is at the time of deposition and become fixed in this direction upon compression.

During metamorphism, sedimentary rocks may undergo marked physical and chemical changes and a permanent magnetization may also be acquired during these changes. This magnetism will be in the same direction as the earth's field at the time of metamorphism.

In the case of the Nairne Pyritic Horizon since the pyrite and pyrrhotite have been formed during metamorphism from what were probably hydrous iron sulphides the present permanent magnetization would have been acquired at this time.

Method of Sampling.

The rock samples used for this work were obtained from the Shepherd's Hill quarry.

Originally it was intended to take samples both parallel and perpendicular to the strike. However, only 2 faces of the open-cut - No. 1 face and No. 3 face - were suitable for collecting specimens.

As work is at present being carried out on No. 1 face it was only possible to collect one specimen (No. 1) from the southern end of this face. Consequently, most of the specimens were obtained from No. 3 face and are, unfortunately, all from approximately the same stratigraphic level, i.e. in No. 3 ore bed.

Difficulty was encountered in collecting specimens because of the many cleavage and joint planes in the rock. These caused specimens to break up when trying to remove them from the face.

Four specimens were obtained from the adit under Shepherd's Hill. Of these four, one was from the quartzite which occurs above the Pyrite Horizon, and one specimen was obtained from each of ore beds I, II and III.

Here, unfortunately, the rock, being unweathered, is very hard and specimens of sufficient size were difficult to obtain. Also, once a specimen was moved, its re-orientation in the same position as it had before removal, was difficult and not altogether exact.

The orientation of the specimen must be known so that the direction of remnant magnetism can be established later. This was done by marking three points on one face of the specimen. Two of these points are in a horizontal plane, and so establish the strike of the rock, while the third point is in the direction of dip. Also, the mine co-ordinance of the position where the specimen was taken were noted.

This was only possible at the Southern end of the mine and thus the positions marked on Map II for the specimens at the northern end of the quarry are only approximate.

To establish a susceptibility contrast, un-orientated specimens were also obtained from the Inman Arkose in the area covered by the ground magnetic traverses north of Harrogate.

Laboratory Work.

From the specimens collected at the mine orientated cores were cut. Usually 2 cores were obtained from each specimen to serve as a check.

Measurements were then made on these cores using the Astatic Magnetometer belonging to the Physics Department.

Two different core sizes were tried.

During the coring of the rock samples, cleavage planes again caused difficulty and it was not possible to obtain cores of the right length from some of the specimens.

The smaller of the two core sizes did not give large enough deflections on the Astatic Magnetometer to give a sufficient degree of accuracy. The larger of the two sizes, namely 35 mm. diameter by 35 mm. in length was, therefore, used for all the actual measurements. Some of these cores proved to be so magnetic as to cause a deflection on the magnetometer even at the largest distance which it is possible to attain between the core and the magnet system (i.e. 17.6 mm.). Due to this, correction for drift of the system between each measurement, was not possible. This could only be done every four measurements and is a possible source of error in the results.

RESULTS.

A table showing the values obtained for each core is given in Appendix III.

The results of this investigation are summarized below.

Range in intensity of Permanent Remnant Magnetism

1.75×10^{-3} to 3×10^{-6}

Range in Susceptibility

2.8×10^{-3} to 2.1×10^{-6}

These results show how variable the Nairne Pyrite Formation is in its magnetic properties.

The declination and inclination of each of the cores is plotted stereographically in figure I.

The specimen obtained from the overlying quartzite (i.e. specimen No. 9) was found to have no permanent magnetism or susceptibility whatsoever. This is to be expected as it appears to consist entirely of quartz.

Specimen No. 3 is from a very weathered micaceous schist which underlies the pyrite horizon at the quarry.

The remnant magnetism and susceptibility possessed by this rock are very small and may be ignored in any calculations of theoretical magnetic

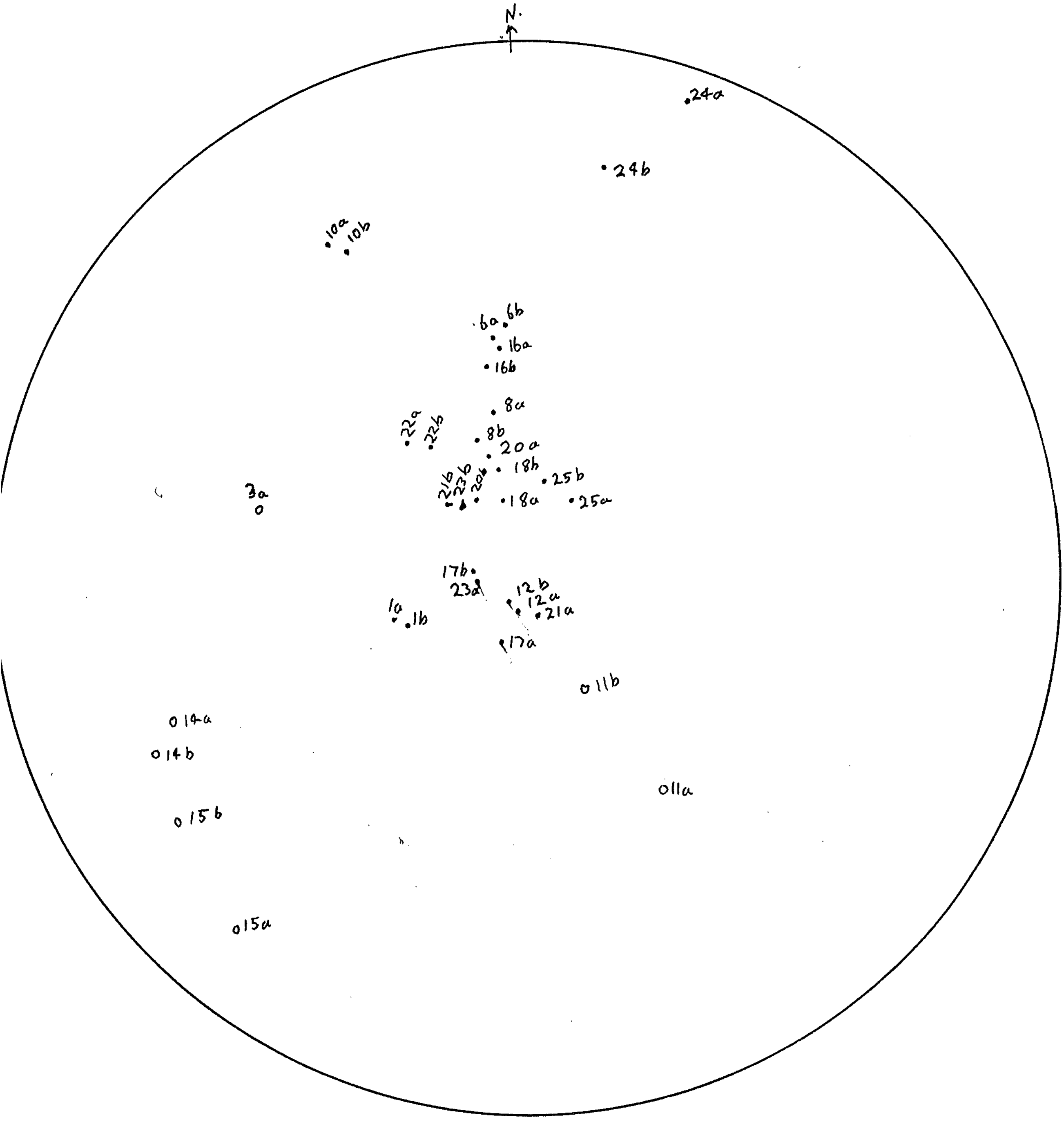
N.
24a
24b
10a
10b
6a
6b
16a
16b
8a
8b
22a
22b
20a
18b
25b
21b
23b
20b
18a
25a
3a
17b
23a
12b
12a
21a
1a
1b
17a
11b
14a
14b
15b
11a
15a

FIGURE I.

profiles over the Nairne Pyrite Formation.

From the stereographic plot it is evident that most of the cores do lie within a fairly limited area.

Most of these specimens come from No. 3 face (which is in No. III ore bed) indicating that at this stratigraphic level at least there is a preferred orientation.

If a statistical analysis is made of the declinations and of the inclinations of those cores obtained from No. 3 face which have a positive inclination, a mean declination of 344^{o} and an inclination of 68^{o} is obtained.

If all the cores having positive inclinations are considered a declination of 338^{o} and an inclination of 64^{o} results.

These directions are very close to those for the present earth's field at Adelaide.

Specimen No. 10 was obtained from the adit and comes from No. I ore horizon. Because it is the only specimen from this part of the sequence no real inferences can be drawn from it.

There are three possible explanations for the directions shown by the two cores.

(1) The beds at this height in the sequence have a slightly different direction of remnant magnetism.

(2) An error in orientation may have occurred due to the difficulty encountered in obtaining and orientating specimens in the adit.

(3) The specimen may have a slightly larger deviation from the mean

value than is usual.

This last remark could also apply to specimen 24 as an error in orientation here, is less probable.

Only three specimens show negative inclinations. Of these, specimen 11 was also obtained from the tunnel and comes from No. 2 face. Possibly the specimen is mis-orientated; however, any error is liable to be small and would not greatly affect the directions shown.

The two cores obtained from this specimen have a greater discrepancy than that which can be safely attributed to experimental error. Unfortunately, another core could not be obtained from this specimen to check the results.

Specimens 14 and 15 were obtained from the southern end of No. 3 face. Therefore, they are from approximately the same stratigraphic level as the other specimens collected from this face, which all have positive inclinations. This could indicate that variations from normal to reversed magnetism may occur over a very short distance.

Although only three of the specimens examined showed reversed magnetization, later magnetic surveys showed this to be an important feature. From this, it is evident that the sampling was not representative of the whole horizon.

To establish the true picture of the magnetic changes across the body, and also to determine whether the normal and reversed components of the remnant magnetism have any preferred orientation, many more samples would have to be taken both along and perpendicular to the strike.

Unfortunately, due to the layout of the open-cut a continuous set of specimens across the formation would be difficult to obtain.

Paleomagnetism

No idea of the direction of the magnetic field during the period when these rocks were metamorphosed can be obtained from these results. Firstly, because of the prescence of reversed magnetization and also because any preferred direction now possessed may be due to the present magnetic field of the earth.

"Washing" the cores in an alternating electric current would get rid of this superficial magnetization but would not destroy the original magnetization derived during metamorphism. If this was done, the results obtained could prove interesting, because comparing the direction of paleomagnetism at Bruckunga with those obtained for different geological periods in other areas of Australia may give an indication of the time of metamorphism of the Kanmantoo Group and thus provide a possible lead to their age.

That the present direction shown by some of the cores may be due to a superimposed magnetization is borne out by the fact that in one of the cores, namely 12b, a variation in the direction of the residual magnetism was noticed over a period of about 6 months.

When the core was measured at the beginning of this period it was found to have a declination of 222^{o} and an inclination of 83^{o}. When re-measured at the end of the 6 month period the declination and inclination had changed to values of 305^{o} and 72^{o} respectively.

This change is better seen from the fact that the inclination actually measured on the core (i.e. before taking into account its dip and strike) changed from $+6^{o}$ to -9^{o}.

These variations although not extremely great are too large to be attributed to experimental error.

Reports also occur in the literature of occasions when the magnitude and direction of the permanent remnant magnetism in a rock have been changed by holding it at an angle to the earth's field and hitting it with a hammer (e.g. Vincenz 1955).

In the present case shocks caused by blasting during mining operations or by hammer blows during the collection of the specimens might have the same effect if the remnant magnetism was at an angle with the earth's.

Although there is no evidence to suggest that this has occurred here, it is an interesting possibility.

Determination of Pyrrhotite and Pyrite

An attempt was made to determine the amount of pyrrhotite and pyrite in each core and thus to derive a graph showing the variations in susceptibility and remnant magnetism with the percentage of pyrrhotite in a sample.

It was hoped in this way to be able to relate the size of a magnetic anomaly directly to a certain percentage of pyrrhotite and pyrite in the rock and consequently to obtain an estimate of the sulphur content. The method tried was to crush the core to -300 mesh (to get a minimum of composite particles) and to separate the pyrrhotite from the rest of the rock magnetically by means of the Franz Magnetic Seperator.

However, the results obtained were useless because separation at this fine grain size was very incomplete.

Talks with the personell at the Bruckunga mine indicated that a fairly accurate determination of the percentage of pyrite and pyrrhotite could be done chemically using the method outlined in Bulletin 95 of the S.A. Department of Mines.

The best method available, however, would be to place a representative crushed portion of each core in a diffractometer and measure the intensity of the peaks on the graph which are due to the pyrite and pyrrhotite. By comparing these intensities with those obtained from a sample containing a known percentage of pyrrhotite an accurate measure of the amount of each sulphide in the unknown sample could be obtained. The only drawback to this method would be the length of time needed to do a sufficient number of samples.

However, neither of the last two methods were tried for 3 reasons.

1. An examination of bore-hole records at the Bruckunga mine showed that the amount of pyrrhotite was practically constant across the whole horizon and the high grade beds (Beds I, II, and III) were determined by an increase in the Pyrite content of the rock. (i.e. there is no relationship between the percentage of pyrrhotite and the percentage of pyrite in the horizon).
2. The poor results obtained from the ground magnetic survey at Harrogate showed that a determination of the amount of pyrrhotite from profiles was impossible.
3. Magnetic surveys at the mine demonstrated the importance of the reversed direction of remnant magnetism and no method of allowing

for the combined effects of different directions of magnetism could be determined.

GROUND MAGNETIC TRAVERSES

Magnetic traverses were carried out using a vertical force magnetometer both at the Bruckunga Mine and over the pyrite horizon where it outcrops two miles north of Harrogate.

Magnetic Survey at Bruckunga.

Three traverses were run at Bruckunga; one over the centre of the open cut and two to the north of the mine area (See Map II).

The instrument used was a Watts Vertical Force Magnetometer. This differs in no important degree from the Schmidt Vertical Force Magnetometer, a description of which can be found in any text book on Geophysics (e.g. Dobrin, 1961).

The traverses were laid out using a tape and compass and were run perpendicular to the strike of the body.

Corrections for diurnal variations were obtained by re-occupying a base station approximately once every two hours and distributing any variation in readings over the time interval between.

Compensation for changes in temperature is automatic and because of the short lengths of the traverses no corrections for normal variations in the magnetic field of the earth were made.

(1) Profile x-x'

One traverse (x-x' ~~Fig.~~ MAP 2) was carried out across the centre of the open cut area (i.e. over Little Hill). Here, the very wide bench allowed practically the whole of the traverse line to be laid out without the necessity of ascending and descending to a number of different levels.

The interval between stations in this case is 50 feet.
The anomaly obtained along the traverse line is shown in Fig. 2 .
Two properties of this figure are immediately apparent.
These are (a) The magnitude of the anomaly

(b) The shape of the profile

(a) The magnitude of the anomaly is due to two factors. Firstly, the body is at the surface and, therefore, only five feet below the instrument. Secondly, it is due to the intensity of the permanent remnant magnetism.

(b) The shape of the curve is due to the fact that the vertical component of the remnant magnetism is alternatively in the direction of the earth's magnetic field and opposed to this direction.

This variation in the direction of the vertical component of the remnant magnetism is accentuated by the small distance between the body and the instrument. Due to this, the greatest force on the magnet system of the instrument comes from that part of the horizon which lies directly below it. This force falls off approximately as the square of the distance from the disturbing magnetic mass to the instrument. Magnetic material a horizontal distance of 10 feet from the instrument will have only approximately 1/100 the effect on the magnetic system as the material directly below it.

Areas where the vertical component of remnant magnetism is positive in direction and areas where this component is negative will, therefore, not interfere with each other to any great extent; thus giving rise to the sharp highs and lows which are actually observed.

The largest value shown by the anomaly is -10,000 gammas and this appears to be produced by a part of the body no more than 20 feet thick. The intensity of the permanent magnetism here was large enough to cause a compass needle to point east-west instead of north-south. If an average susceptibility of 1.2×10^{-3} is assumed for the horizon an anomaly of this magnitude would require a remnant magnetism of 4×10^{-2} oersteds. This shows that the reversed direction of remnant magnetism, although not brought out by the cores, is an important factor.

Unfortunately, it was not possible to obtain any specimens from this part of the horizon. Figure 3 is a theoretical anomaly over the formation assuming a susceptibility of 1.2×10^{-3} and no remnant magnetism. A constant susceptibility across the horizon can be assumed because the variations in the percentage of pyrrhotite are so small as to be insignificant for this purpose. Evidence for the attitude of the body was obtained from boreholes. Calculations show that the horizon here, is 420 feet wide and dipping at an angle of 70^{o} to the east. The depth extent was taken to be infinite.

The unusual shape of the profile over the horizon itself is due to the width and extreme shallowness of the body. Note that the greatest value of the anomaly is less than 500 gammas compared with the maximum values of +6,000 gammas and -10,000gammas actually obtained.

Also the negative part of the curve which occurs to the west of the body on the theoretical profile does not occur on the actual profile, due, probably, to the large positive component of remnant magnetism occuring just at the edge of the pyritic formation.

(2) Profile z-z'

Another traverse (z-z' Fig. 4) was laid out to the north of the actual open cut. Here the pyritic horizon outcrops over a distance of at least 600 feet and, being more resistant than the surrounding micaceous schists forms a fairly large hill.

The formation at this point strikes magnetic north-south. The traverse line was, therefore, laid out magnetic east-west and stations were established at 100 foot intervals.

Diurnal variations were allowed for by re-occupying a base station every 1½hours.

The curve obtained by plotting vertical intensity values against the station interval is shown in Figure 4 . Some of the readings, of course, were taken on the sides of the hill. Consequently, for these readings, the 100 foot station interval is not the true horizontal distance between readings. A slope of 20° was assumed and the appropriate slight adjustments were made to the stations concerned. This corrected profile is plotted in Figure 5 .

This curve may be divided up into three major parts as shown. The small maximum to the east of the highest peak is believed to be due to a fence about 10 feet from the point where the reading was taken and has, therefore, been ignored.

The average depth of weathering over the mine area is 30 feet. If this is added to the distance between the ground and the instrument (5 feet), an average depth of 35 feet to the top of the body producing the anomaly is obtained.

Using this figure it is possible to plot three theoretical bodies which, when combined would produce the anomaly shown. (See Figs. 5 and 6).

These three bodies would have the following dimensions and susceptibility.

(1) Depth = 35'
Width = 240'
Susceptibility = 1.49×10^{-3}

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(2) Depth = 35'
Width = 320'
Susceptibility = $.82 \times 10^{-3}$

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(3) Depth = 35'
Width = 190'
Susceptibility = $.64 \times 10^{-3}$

The thickness of the bodies is assumed to be infinite.

The discrepancy between the observed curve and the theoretical curve between bodies (1) and (2) could be eliminated by assigning a small value of susceptibility to this part of the horizon.

This would give a theoretical width to the body of about 820' which is larger than the actual width.

The values of susceptibility for each body which are needed to produce these theoretical anomalies lie within the range of susceptibilities determined from the cores and the three peaks on the profile could be due to changes in susceptibility across the body.

In this case it would be assumed that the vertical components of the normal and reversed directions of remnant magnetism in the horizon would cancel out at this distance above the horizon. However, as mentioned before, the percentage of pyrrhotite in the formation is thought to be sensibly constant. Therefore, it would appear that, more likely, the apparent variations in susceptibility are due to incomplete cancellation of the various components of the permanent remnant magnetism.

If an average susceptibility of 1.2×10^{-3} is assumed, the residual vertical component of permanent magnetism needed to produce anomaly one would be in a positive direction and would have a value of 1.6×10^{-4} oersteds.

For bodies 2 and 3, the vertical component would be in a negative direction and would have values of 2.1×10^{-4} and 3.1×10^{-4} respectively.

In this theoretical analysis it has been assumed that the horizon can be divided up into three discreet bodies. Changes in the direction and magnitude of the remnant magnetism are probably more rapid than this. On the profile along the line (x-x'), the value of the anomaly changed from +6,000 gammas to -10,000 gammas over a distance of only 20 feet on the Western side. On the eastern side of the anomaly, however, the variation from +5,500 gammas to -1,100 gammas occurred over a distance of 200 feet. Therefore, the splitting up of the anomaly along line (z-z') into three bodies separated by sharp vertical boundaries is only useful for deriving a theoretical curve. The three bodies and the changes associated with each one are more likely to merge gradually into each other. This gradual merging of the bodies would explain the discrepancy between the curves in the area between bodies (1) and (2).

The horizon at this point is thought to dip steeply to the east. Some evidence of this dip is shown by the slow tapering off on the east side of the profile obtained in the field.

This dip was not taken into account when plotting a theoretical profile because of the length of time which would be needed for the calculations.

This theoretical curve is not intended as a solution to the actual body producing the observed profile. It does show the effect which remnant magnetism can have. In this case the theoretical solution obtained is close to the correct answer. The theoretical body is wider than the actual one and is vertical instead of dipping steeply east. However, in cases where the remnant magnetism has a greater magnitude and a more constant direction, a theoretical analysis not taking this into account, could lead to an entirely wrong answer.

(3) Profile y-y'

Traverse y-y' was carried out along the road as shown on Map II. The results are plotted in Fig. 7 . Here again the effect of the remnant magnetism is clearly visible and this profile does not lend itself to a theoretical analysis.

Horizontal Force Magnetometer.

Readings with a Watts horizontal force magnetometer were also taken along the traverse line (z-z'). The results are plotted in Fig *8* . No corrections for the slope of the hill have been made in this case.

This profile is of little or no use; due to two main reasons.

(a) The horizontal component of remnant magnetism may be directed towards any point of the compass. Accordingly, unless there is a preferred direction for permanent magnetization, the resolved part of this horizontal vector in the direction of the magnetic meridian could be expected to vary widely in magnitude and be either north or south in direction.

(b) The high magnetic latitude (70°) at which the deposit lies. The horizontal value of the earth's field at Bruckunga is, therefore, only .22 oersteds (c.f. .56 oersteds for the vertical field). Variations in the horizontal field produced by any body having an anomalous magnetism would, consequently, be only about 1/3 as great as the variation in the vertical component of the earth's field.

Magnetic Survey in Harrogate Area.

A magnetic survey was also carried out approximately two miles north of Harrogate. Here the Nairne Pyrite Formation forms a low but conspicuous outcrop striking roughly north-south (See Map III).

Geology.

The rocks in this area are dipping to the east at approximately 60°.

To the west of the horizon the outcrops are formed by a meta-arkose. This is probably the Inman Arkose; a facies equivalent of the Quartz-Biotite Schists, which are the main rock type in the area.

Stratigraphically overlying the pyrite horizon is a very micaceous schist which weathers rapidly and forms little outcrop. Minor amounts of quartz also occur but these appear to be float and no solid outcrop was seen.

There are actually 2 pyrite horizons in the area, about 850 feet apart. The actual position of the stratigraphically high one is not well defined. No outcrop which was obviously in place was visible. The two outcrops of the upper horizon shown on the map occur on the tops of two small hills and a certain amount of scree on the sides of these is to be expected. The horizon, here may therefore, be quite narrow and may lens out at either end or even between the two hills.

Outcrop along the lower horizon is relatively continuous and the formation can be followed for many miles along the strike in both directions.

Contacts between the pyritic beds and those below and above are not visible. The lower horizon appears to vary between 100 feet and 150 feet wide. The width of the upper horizon is not known.

Where seen at out-crop, both horizons have weathered to a red, limonitic gossan. The depth of this weathering is not known.

Magnetic Survey.

In all, six traverse lines were laid out. These lines were run magnetic east-west using a tape and compass.

Along each of these lines, stations were pegged out at 50 foot intervals.

The six lines - designated A, B, C, D, E, F - are 400 feet apart, covering in all a distance of 2,000 feet along the strike.

Lines A and B, which are at the southern end of the area considered, are 1,200 feet in length. These cover only the main pyritic horizon, extending for 600 feet on either side of it. The other lines - i.e. lines C,D,E,F - are each 1,800 feet long. As well as covering the lower horizon, lines D and E cross the upper horizon where it is known to outcrop. Lines C and F are to the south and north respectively of the area over which the upper horizon outcrops. The purpose of these lines being to establish if the horizon continued in either or both of these directions.

The actual layout of these lines can be seen on Map III A.

Two separate instruments were used during this survey. The first was a Ruska Vertical-Force Magnetometer, belonging to the Physics Department. Before use in the field, this instrument was calibrated using a pair of Helmholtz coils and was found to have a sensitivity of 13.1 gammas per scale division.

This degree of sensitivity may appear high and is due to the fact that the magnetometer was originally intended for use in oil search rather than for mineral surveys.

This high sensitivity proved to be an advantage in the Harrogate area because of the small anomalies which were found to exist. However, due to wear on the knife-edges it was difficult to reproduce the same reading on different occasions at any particular station with this magnetometer.

Therefore, it was necessary to take the average of a number of readings to obtain a sufficient degree of accuracy.

A Watts Vertical-Force Magnetometer was also used. This magnetometer was also calibrated by means of the Helmholtz coils. The sensitivity was calculated to be 31 gammas per scale division, which is the usual order of sensitivity for mineral exploration.

Procedure.

Readings were taken at each station.

The Ruska magnetometer was used to survey lines A, B, C, D, E and the Watts Magnetometer was used along line F. Also the Watts Magnetometer was used to check a number of the readings at stations along those lines originally surveyed with the Ruska.

Corrections for diurnal changes were made by re-occupying a base station on each line at regular intervals and distributing the variation over the stations occupied in the interval.

These base stations were later tied together in the one traverse using the Watts Magnetometer. Readings along each line were adjusted accordingly. In all over 190 different stations were occupied,many of these more than once.

The values obtained for the vertical magnetic intensity at stations along each line were plotted and the results shown as profiles (See Figs. 9 to 14).

An attempt to produce a contour map of the values was found to be impossible.

Results.

An examination of the profiles obtained shows that the Nairne Pyrite Formation does not give rise to any anomaly of the size which would be expected. In fact, on some lines there are no anomalies which even appear to be associated with it.

The greatest values of vertical magnetic intensity are actually obtained over the Inman Arkose which borders the horizon to the west. This is especially evident in those areas where the arkose actually outcrops.

Samples were taken from one of these outcrops and three cores (H1a to H1c) were taken from these samples. However, tests on these cores showed the values of permanent remnant magnetism and susceptibility possessed by the arkose to be negligable, compared with those for the pyrite formation.

Also examination of a slide of the rock in transmitted light showed that only a minor amount of magnetite was present.

An unusual feature of some of the profiles is their "saw-toothed" nature; caused by the fact that readings rise and fall rapidly from one station to the next. This may be due to banding within the pyrite horizon itself; however, it is more likely due to the poor knife-edges of the Ruska Magnetometer: for this reason it might be better to consider a smooth curve through the values actually obtained.

An examination of profile A, shows that the largest value of magnetic intensity occurs on the western side, where the Inman Arkose forms a large outcrop.

The profile then dips sharply over an area where there is no outcrop and where, presumably, the soil cover is fairly deep.

Over the horizon itself the profile rises fairly sharply to a peak, which appears to be caused by the pyrite formation. This peak is, however, 50 to 60 gammas less than the intensity over the arkose.

On the east the profile rises slowly. No outcrop occurs on this side and the cause of the rise is not known. The sharp peak near the eastern edge is probably due to some buried Iron object at this point.

Line B shows a similar curve to line A but the rise in intensity values over the horizon is not as sharp.

On line C a slight hump occurs over the horizon but no real significance can be attached to it. The profile does show up very clearly the effect that fences can have on the magnetometer.

The only anomalies that really appear to be caused by the two pyrite horizons occur on lines D and E. Even here the intensity of the peaks is not as great as that caused by the arkose. The effect of fences is again clearly visible.

The profiles obtained along these two lines are much smoother than those along the other three lines surveyed, using the Ruska. In spite of this a theoretical analysis of these two curves does not seem justified.

The higher values of intensity obtained over outcrops of the Inman Arkose is also evident on line F. Over the pyrite horizons themselves there is no anomaly produced. The increased values of intensity obtained between the two lines may be due to the combined effect of the two horizons. However, the higher of the two horizons does not actually outcrop along this line.

At the western edge of line E the profile shows a very sharp fall of about 140 gammas. The sharpness and magnitude of this dip indicates that it could be caused by a fault.

This rapid decrease in magnetic intensity is also visible at the western edge of Line F.

A fault drawn through these two points lines up rather well with the course of the river. This might indicate that its course is controlled by a fault approximatley along this line. Further evidence for the existance of a fault is given by a sudden and quite large increase in the slope of the ground in this position.

A residual profile was plotted for line D because the pyritic horizon appeared to have the most effect on the magnetic profile along this line. By this means it was hoped to sharpen up any anomalies which might be due to the horizon. The results of this calculation are plotted in fig. 15 . Obviously nothing of value can be obtained from such a plot in this area.

Although a slight rise in magnetic intensity occurs over the horizon on many of the lines, it is obvious that an anomaly of the size which would be expected from the values of remnant magnetism and susceptibility possessed by the horizon, does not occur.

The absence of any anomaly over the Nairne Pyrite Horizon in this area could be due to five different reasons.

These are:

(1) Absence of pyrrhotite

(2) Degree of weathering of the pyrrhotite

(3) Effects of permanent magnetism

(4) The surrounding rocks are more magnetic

(5) Masking effects due to more magnetic features at depth.

(1) At this particular part of the horizon conditions may not have been suitable for the formation of the hydrous Iron Sulphides from which the pyrrhotite is formed. Also, because the horizon here is relatively narrow, the total amount of pyrrhotite would be less than at Bruckunga and consequently a smaller anomaly would be expected.

(2) The pyrrhotite in the horizon weathers very rapidly, much more rapidly than the pyrite, and so the depth at which fresh pyrrhotite occurs may be fairly great. Also the limonite gossanous crust which forms over the top of the horizon may have a masking effect on the magnetic force.

Calculations show, however, that to produce no anomaly at all the effective depth of burial of the top of the formation would have to be at least 300'. Even if this value is out by 50% to 60% it is unlikely that the absence of any anomaly is due solely to this cause.

(3) In this area, as at Bruckunga, the effects due to the different intensities and directions of the remnant magnetism may not

cancel out completely. If the direction of the vertical vector due to this remnant magnetism was opposed to that of the earth's field, and the intensity of the remnant magnetism was sufficiently large, the two vectors may tend to annul each other.

The shape and size of the anomaly actually observed over the horizon would depend on the magnitude and direction of the remnant magnetism; the degree of cancellation of the vertical fields due to the remnant magnetism and to the earth's field, and the width and effective depth of the pyrite horizon.

(4) Determination of the magnetic properties of the Inman Arkose has been mentioned previously and it is evident that this is not as magnetic as the pyrite horizon.

(5) It does not appear possible that the shape of the profiles are due to magnetic material at depth. Such material would cause a much broader anomaly and might show up on the profiles as a steady gradient in one particular direction. The features due to mean surface bodies would be superimposed on this general gradient.

Although there is no real evidence to suggest that the amount of pyrrhotite in this area is less than in other parts of the horizon, this would appear the most likely answer for the absence of a distinctive anomaly.

The second, and perhaps the third, suggestions put forward are also probably contributing factors.

AEROMAGNETIC MAPS

Three different aeromagnetic maps covering the horizon were examined.

These maps were made available by the S.A. Department of Mines. The actual air-borne magnetometer survey was conducted by Adastra Hunting Geophysics Limited.

The total magnetic intensity at 500 feet above the ground was recorded continuously. Uncontrolled photomosaics assemblies were used to navigate flight lines and, for subsequent compilation of maps, the actual flight course was recorded on overlapping photographs taken with a 32m.m. Vinten camera during flight.

The actual plan for use as a base map was compiled from semi-controlled photomosaics at a scale of approximately 1 mile to 1 inch.

Reduction of results was carried out by the Geophysical section of the S.A. Department of Mines.

The maps examined were:

(1) Total intensity magnetic map of the Murray Lands. The scale of this map is 4 miles to the inch, which is too small to show any detail in the area where the Nairne Pyrite Formation outcrops.

(2) A one mile to the inch map, constructed from the above 4 mile map. Due to a flight line spacing of 4 miles, there was insufficient control to delineate the anomalies due to any horizon as narrow as the Nairne Pyrite Horizon. The map does show, however, the

broad regional variations in magnetism and the general north-south trend of the magnetic features.

(3) Total intensity magnetic maps of the Adelaide and Echunga geological sheets and the parts of the Mannum and Mobilong sheets which were covered during the same survey. This survey was flown along ~~the~~ east-west flight lines at a line spacing of one mile.

Corrections for regional gradient have been applied in this case.

A composite map (Map I A) was drawn from these sheets to cover the northern area in which the pyrite horizon occurs. A geological map of the corresponding area constitutes Map I.

Examination of Map.

On the map itself (Map I A) the general trend of the pyrite horizon is distinct.

On the western side of the Bremer Fault the horizon gives rise to a broad anomaly which trends in a roughly north-south direction.

Between Harrogate and Nairne the trend of the horizon is not so distinct. A large anomaly with a maximum value of 1,960 gammas in this area may be due partly to the magnetic properties of the horizon. However, the general shape of the contours, especially the flatness of the gradient on the western side, indicates that the feature is also partly due to a more deep-seated source.

Over the Bruckunga mine the pyrite horizon gives rise to a distinct anomaly (Fig. 16). Further down on the Echunga sheet the formation is again outlined by a north-south trend of the magnetic contours but this trend is not as distinct as it is further north.

In general the anomaly on the western side of the Bremer Fault appears to be displaced slightly to the west of the area over which the horizon actually outcrops. As the dip of the horizon, over most of its length, is to the east, this is a surprising feature.

A possible reason is that the horizon in this area possesses a remnant magnetism whose declination is directed towards the west. However, at this height it is likely that the various components of the remnant magnetism would tend to cancel one another out completely. This would mean that the anomaly would be entirely due to the susceptibility of the horizon and consequently the anomalous magnetic vector would be in the same direction as the earth's field, i.e., magnetic north.

The only other reason which can be thought of to explain this feature is that the base map on which the magnetic field intensities were plotted is slightly inaccurate. As the base was compiled from uncontrolled photomosaics, this may well be the case.

On the eastern side of the Bremer fault the horizon also shows up clearly on the magnetic trends although along most of its length it does not actually outcrop. Here the anomaly is much narrower and consequently the contour gradients on each side are steeper. Towards the southern end the anomaly becomes more complex due to folding of the horizon in this area.

The closed peaks which occur within the general linear trend can be attributed to variations in susceptibility within the horizon itself. Such even at the low height at which the lines were flown.

No evidence for the existance of the Nairne Fault which supposedly seperates the Kanmantoo metamorphic rocks from the sediments of the Adelaide System is visible on the aeromagnetic map in this area. Lower down on the Echunga Sheet, however, this fault gives rise to a very strong linear trend. The beginnings of this trend can be seen in the south-western corner of the aeromagnetic map.

A more detailed analysis of the anomalies produced by the pyrite formation will be given later by considering a number of profiles across the horizon.

Second Derivitive Map.

A second derivitive map covering that part of the aeromagnetic map outlined was plotted and is shown in Map I B. Unfortunately, the length of time involved in plotting second derivitive maps made it impossible to cover the full area. Therefore, only the area on the western side of the Bremer Fault, along which the Nairne Pyrite Formation outcrops was covered.

The formula used has been derived by Henderson and Zeitz (1949).

This map was plotted using 2 circles of radius, one mile and 2 miles respectively. Values were plotted for the corners of a $\frac{1}{2}$ mile grid which covered the area concerned. The values shown on Fig. IC are $\frac{1}{4}$ of those actually derived. This makes the map easier to contour. Contours were drawn at an interval of 20 gammas / square mile.

Part of the map was first derived using circles of radii $\frac{1}{2}$ mile and $\sqrt{2} \times \frac{1}{2}$ mile. This gave rise to many local closed highs and lows and a larger unit radius was therefore used. However, the position of the zero contour line is in approximately the same position for both grids.

variations would reflect changes in the percentage of pyrrhotite in different parts of the body along the strike.

Due to the fact that the flight lines are east-west and, therefore, perpendicular to the strike of the horizon, the control on the shape and intensity of the anomaly is very good.

The Nairne Pyrite Formation is the only feature on the map which shows up clearly. Most of the area is characterized by broad open contours showing that the gneisses and schists which constitute most of the area do not contain any great amount of magnetic material. Overall the general north-south trend of the contour lines do indicate that the main structural trends are also in this direction. However, this feature is, by no means, marked. On the eastern edge of the map a closed high of 2,000 gammas can be attributed to an outcrop of the Palmer-Granite.

The broad anomaly in the north-west corner and the intense low associated with it is on the eastern edge of the very large anomaly caused by the Houghton Barossa Archean linear which lies just to the west of the area shown in the geological map. Although Archean rocks do not actually outcrop in the area covered by the anomaly, they must be very close to the surface.

The Bremer Fault which is clearly visible on the geological map as a large crush zone is not visible at all on the aeromagnetic map. This is to be expected, because it is known there is no development of magnetite along this crush zone. The main iron mineral present is haematite which has a very low susceptibility and could not be expected to produce any effect, A 4th-derivitive map was not attempted because the flight line spacing of 1 mile does not provide sufficient control.

At the northern end of the map, the pyrite horizon is clearly delineated and is in the same position as the anomaly on the aeromagnetic map. The trend of the contours here is more towards the north-east and an examination of the geological map shows that the horizon does swing towards this direction at its northern end.

Also the large anomaly between Harrogate and Bruckunga is resolved into a linear north-north-east trend, which shows a close correlation with the assumed position of the pyrite horizon in this area. Apart from these two cases the 2nd derivitive map does not produce any sharpening of the anomaly over the formation.

An unusual feature of this map is the predominance of north-east and north-west trends. This is especially marked because almost all of the anomalies are long and narrow in shape. Geological mapping in the area has shown that most of the rocks strike north-south and the thought arises that perhaps these trends are due to a more deep seated cause. The grid spacing of 1 mile would also tend to make the more deep-seated anomalies stand out relative to those which have their source closer to the surface.

Actually this pattern of roughly north-east and north-west trending linear patterns is known to be common both on many total intensity aero-magnetic maps and on 2nd derivitive maps throughout Australia. The cause of these trends is not known but it is believed that the Bureau of Mineral Resources has shown an interest in this feature and is at present looking for some common cause.

Profiles.

A number of profiles across the pyrite horizon will be examined to obtain some idea of the shape and the depth of the body.

The linear trend of the body has already been pointed out and it is safe to assume, for the purposes of analysing the profiles, that the horizon is infinitely long in one direction.

Profile A-A' (See Fig. 17)

This profile through the anomaly is to the north of the area over which the horizon actually outcrops. On the map it appearsas a simple anomaly containing no subsiduary peaks.

The profile is taken along one of the flight lines because experience has shown that there is usually insufficient control between flight lines to give accurate depth estimations.

On the second derivitive map the strike of the anomaly is about 25^{o} magnetic.

Ignoring the two minor humps on the eastern side of the profile, the general shape of the body indicates a body dipping to the east. The sharp gradient on the eastern side on the anomaly shows that this dip is fairly steep. Also, because the extended curve on this side does not dip below, the base contour level which has been taken as 1,680 gammas, the depth extent of the body can be assumed to be infinite (or at least greater than the distance from flight-level to the top of the body).

Depth calculations on this anomaly were carried out using three different methods. All of these calculations are subject to error due to the dip of the horizon.

½ Width Method.

This method should give a reasonably accurate answer because of the high magnetic latitude at which the horizon occurs.

The half-widths of the anomaly are .7 inches and .85 inches to the west and east respectively. (The horizontal scale of the profile is 1"=2,640')

A depth range of from 1,850 feet to 2,250 feet below flight lines, was obtained. That is 1,350 feet to 1,750 feet beneath ground level.

Smellie's Method.

The ratio of the two half widths is equal to .82. The theoretical value given for a line of poles is .85 and for line of dipoles, .87. Thus the body is best approximated to a line of poles and confirms the fact that the body can be regarded as infinitely deep.

Using the formula given by Smellie (1956) a depth of 2,050' is obtained. (i.e. 1,550' below the surface of the ground).

2nd Derivitive Map.

The model analysis of Vaquier et al (1951) was used. Two models given by them could apply in this case.

The characteristics of these are as follows.

(1) Dimensions - 1 x 6

Inclination - 75°

Strike - magnetic north-south

(2) Dimensions - 1 x 6

Inclination - 75°

Strike - N 45° E

The choosing of any model for this anomaly is open to doubt because it is not really isolated and does not have a closure at the northern end.

Also there are two centres of polarization within the anomaly itself. However, these two factors are not likely to cause any great degree of error in this case.

The b-index on the curvature map was used to estimate the depth. Values given by the 2 models were 2,250' and 2,200' respectively. (i.e. 1,750' and 1,700' below the surface). Values of 2,250' and 2,400' were obtained for the width for the north-south and skewed modes respectively.

Although the depths derived by these different methods are subject to error because of the approximations which have to be made, they do indicate that the body is a little over 2,000' below flight level (i.e. 1,500' below the surface of the ground) and in the order of 2,300' wide.

Using these approximate limits as a starting point, theoretical anomalies were plotted for various values of susceptibility and various angles of dip. The closest fit to the actual curve was obtained using the following values.

Width = 2,000'

Depth below flight line = 2,000'

Dip = 60^{o}

Susceptibility = 2.2×10^{-3}

A closer fit might be obtainable by judiciously adjusting the various values. Because there are four largely independent variables involved, the calculations involved would be long and tedious. However, the theoretical body derived above would have values of the right order.

Therefore, if no geological evidence for the area is available, interpretation of the aeromagnetic data would lead to the above result.

However, if we assume that the anomaly is due to the Nairne Pyritic Formation, and this appears to be a reasonable assumption, the geological map shows the following facts.

(1) The anomaly from which the profile has been derived is to the north of the area where the pyrite horizon outcrops.

(2) The pyrite body outcrops at the surface and is, therefore, of the order of 500' below flight level.

(3) The horizon is nowhere in this area greater than 400' thick.

(4) At the northern end of outcrop there are at least two pyrite bands and these have been subjected to folding.

When these points are considered, an explanation for the anomaly produced is evident.

The inclination of the earth's field in this area is 70°. Therefore, the total intensity anomaly produced by the formation will not occur directly above it but will be displaced to the north for a distance determined by the depth below the flight line and this angle.

However, the magnitude of this displacement is far greater than that which would be expected from theoretical considerations. This could be due again to a faulty base map and also the anomaly may be due to some other cause besides the Nairne Pyrite Formation.

Neither of these statements is considered to be the true cause, however, and the real reason is not known.

The width of the anomaly is caused by the folding.

K. Kappelle (personal communication) has in this area mapped 3 pyrite horizons folded into a synclinal structure plunging towards the south. The distance between the horizons is approximately 500'. Calculations show that anomalies due to two magnetic bodies less than 560' apart will, at a height of 500' above them, merge to give only the one anomaly without any subsiduary peaks. (Note that bodies a slightly greater distance than this apart will also give rise to only one peak unless a flight line passes directly over the centre of this peak). Merging of these bodies to produce one wide anomaly will give rise to erronous values derived for the depth. The high susceptibility of 2.2×10^{-3} which is almost twice the average value for the formation would be caused partly by the same effect.

Profile B-B'. (Fig 18)

This profile is across a more symmetrical part of the anomaly. The slight broadening of the contours on the eastern side of the anomaly would again be due to an easterly dip. No corresponding low occurs on the western side indicating that this dip is fairly steep.

Depth determinations by ½ width formula give a range from 1,050' to 1,350' below flight level (i.e. 550' to 850' below surface).

The ratio of $\frac{n}{n'}$ = .67 which is very low for a line of poles striking north-south and Smellies method is, therefore, not applicable in this case.

The shape of the anomaly on the second derivitive map in this area is not of a sufficiently distinctive shape to allow correlation with any of the models given by Vaquier.

A theoretical body which would give rise to the anomaly is also plotted in figure . The dimensions of this body are:

width = 760 feet

depth below flight level = 1,000 feet

susceptibility = 1.2×10^{-3}

The discrepancy between the two curves on the eastern side is caused by assuming a vertical attitude for the theoretical body.

Here again both the width and the depth vary greatly from those known for the horizon. The assumption must be made that here also two pyritic bands less than 560' occur. Mapping by N. Marshal in this general area has shown two main pyrite bands, but, over most of their length the distance between them is greater than 600'.

For comparison the magnetic anomaly which would be produced by a vertical body 260' wide, 600' deep and having a susceptibility of 1.2×10^{-3} is also plotted on the figure. This is the anomaly which might theoretically be expected.

Profile c-c' (Fig. 19)

This profile is drawn across the pyrite horizon in an area where it gives rise to no distinct anomaly.

The area covered in the ground magnetic traverse is slightly to the north, but a very similar profile having a somewhat greater value would be obtained there. Notice also that the Bremer Fault has no recognizable effect on the anomaly.

The two large anomalies on the eastern side of the profile may be due to two pyritic horizons whose centres are about 2,500' apart.

There is no real evidence for this on the geological map. The distance between the anomaly and the area where pyritic beds outcrop further to the south precludes any correlation between the two. A northerly shift in the anomaly of this magnitude appears impossible at this high inclination and shallow depth.

However, if the assumption is made that the anomaly across which profile A-A' has been taken, is due to the pyritic bands to the south of it; then the possibility does arise that at similar phenomenon occurs here also.

Determinations of the depth and size of the bodies producing the anomalies are not possible for two reasons.

(1) The interference between the two anomalies

(2) The difficulty of establishing a back-ground level for this region.

The general symmetrical shape of the profile does suggest that the horizons are vertical.

Profile D-D' (Fig. 16)

This profile is along a line passing over the mine at Shepherd's Hill.

The large anomaly to the west of the profile is the beginning of the distinctive linear trend attributed to the Nairne Fault.

Over the mine itself, the formation gives rise to a well-defined high. To the west of the mine a distinct gradient is visible. A profile over the mine corrected for this gradient is shown in fig. 20. On this figure the anomaly has a magnitude of only 80 gammas. The actual anomaly expected is much larger than this and it is probable that the actual base level for the anomaly is much lower than that shown. Because of this no attempt to derive a theoretical body from this curve has been made.

Profile E-E' (Fig. 21).

Profile E-E' was drawn across the anomaly on the eastern side of the Bremer Fault in an area where the trend of the profile is obvious.

Also the steepness of the contours and the lack of closed highs indicates that the anomaly is due to a single magnetic feature.

The general symmetry of the profile shows that the horizon is more or less vertical.

Base level for the anomaly was assumed to be 1,650 gammas and the strike of the feature is 135°. Using these figures, the following values for the depth were obtained.

<u>Half-width formula</u>

This method gave a range of 800feet to 1,050 feet below flight level.

<u>Smellie's Method</u>

The ratio $\frac{n}{n'}$ is .75 which is quite close to the theoretical value, for this inclination and strike, of .78. The depth determined was 930' below flight-level.

Peter's Slope Mæthod.

Because the horizon is known to be fairly narrow, the formula used in this case was:-

$$S = 1.4\ h.$$

This gave a value of 940' below flight level. (400' below ground level).

An average value of about 930 feet can be assumed. As this anomaly is almost certainly due to a single pyritic band, the depth of weathering of the pyrrhotite may be greater in many areas than the 30 feet which occurs at the mine. The pyrrhotite is known to weather very easily and certainly the length of time since its formation is adequate to permit extensive weathering.

However, it seems unlikely that this weathering would extend to a depth of over 400 feet.

From consideration of the profiles it is obvious that theoretical calculations on them, when there is no geological control available can lead to erronous results.

This is especially evident on the eastern side of the Bremer Fault where the anomaly is much broader than would be expected. Possible causes of this width have been given above.

There are other explanations for this phenomenon. Often when a body crops out at the surface a slight broadening of the anomaly occurs. This would be especially so in those places where the pyritic formation stands out above the general level of the other rocks.

Here the broadening would be due to the combined effect of the extra material exposed on the sides of the hill and also to the reduction in distance between the plane and the ground. The closed highs which occur along the horizon could also be partly due to these large outcrops.

(A better idea of the effect of topographical changes could be obtained by downward continuation of the total intensity contours to the ground surface. However, the length of time involved in doing this is a prohibitive factor.).

Another explanation for the broadness of the anomaly is that it is caused by magnetic bodies lying below the Nairne Pyrite Formation itself. The closeness with which the anomaly follows the outcrop of the horizon is the main argument against this idea. An increase of the amount of pyrrhotite with depth, perhaps due to a higher grade of metamorphism is an explanation which although possible, does not appear probable.

OTHER GEOPHYSICAL WORK.

Electromagnetic

During the year the S.A. Department of Mines carried out an electromagnetic survey across the Nairne Pyrite Formation, in which the writer took part.

The purpose of this survey was to test a set of equipment which had just been built by the department.

Briefly the method consists of passing a fairly high frequency alternating current into the earth by means of two electrodes about 2,000 feet apart. The field produced by this current is measured by two search coils consisting of several hundred turns of copper wire which are connected 200 feet apart.

In the absence of an ore body the amplitude and phase of the signal picked up by both coils will be the same.

If an ore body is present below the surface of the ground, the secondary field produced by it, will distort the primary field due to the alternating current.

Depending on their position in relation to the body, the effect of this distortion on the two search coils will be different. The difference in amplitude and phase of the signal picked up by the two coils is measured and plotted as profiles.

Unfortunately, the results of this survey were not kept by the Mines Department; however, it is known that the pyritic formation gave rise to a very distinctive anomaly.

Gravity.

Measurements made on the cores from the Bruckunga Mine showed the pyrite horizon to have an average Specific Gravity of 3.0. The cores obtained from the arkose north of Harrogate showed an average S.G. of 2.5. Thus, although these densities will vary somewhat at different places along the strike, there is a density contrast of the order of .5 between the horizon and its surrounding rocks.

With such a high contrast as this, a large anomaly could be expected over the Nairne Pyrite Formation, and gravity methods could be used in exploring for the horizon.

This would necessitate, however, the surveying of all the stations so that their altitudes would be known for use in the reduction of results.

CONCLUSIONS.

Most of the conclusions have been drawn at the end of each section, and only a summary will be given here.

(1) The susceptibility of the horizon, although variable, is greater than that of the surrounding rocks.

(2) The permanent remnant magnetism possessed by the horizon may be positive or negative in inclination.
Whether there is a preferred orientation for these positive and negative components is not known.

(3) Ground magnetometer traverses may be affected by this remnant magnetism if the depth of weathering is not great compared with the width of the formation.
At the altitude at which the aeromagnetic work was flown, the various components of remnant magnetism may be assumed to annul each other.

(4) In places ground surveys using a vertical-force magnetometer may not reveal the presence of the horizon.

(5) The interpretation of aeromagnetic maps must be carried out with caution.
In general any anomaly shown on these maps should be checked on the ground by other geophysical means.
Although neither method has been proved successful in this case, it is suggested that electro-magnetic or gravity methods might be tried.

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APPENDIX I.

THE ASTATIC MAGNETOMETER

The astatic magnetometer has been in use for nearly one hundred years in the measurement of weak static magnetic fields.

In 1952, Blacket developed a particularly sensitive astatic magnetometer, making it possible to measure the magnetic properties of weakly magnetic sedimentary rocks. This lead to its wide-spread use in the field of paleomagnetic research.

An astatic magnetometer is essentially a magnetic gradiometer. The magnet system consists of two parallel, horizontal and oppositely opposed magnets of nearly equal moment P. These are rigidly connected 10cms. apart and the whole suspended vertically by a phosphor bronze strip.

A uniform horizontal magnetic field has no effect on the magnetometer, because the moments of the magnets are equal and act in opposite directions. Similarly a vertical magnetic field will also have no effect as it cannot cause rotation in a horizontal plane. Therefore, only a horizontal field possessing a gradient will cause rotation.

If the difference at the magnets between the horizontal field components at right angles to their axis is h, a deflection θ of the suspended magnet system will occur.

$$\text{The sensitivity } s = \frac{\theta}{h}$$

$$= \frac{T^2 P}{4\pi^2 \alpha \, I_o}$$

When I_o and αI_o are the moments of inertia of one magnet and of the whole system, respectively about the vertical axis and T is the period of oscillation in the abscence of a field gradient.

Although the sensitivity is proportional to T^2, the period of oscillation should not be too large. Sixteen deflections must be measured to determine the divertion and intensity of the permanent remnant magnetism of a core. Measurement of the susceptibility requires another eight readings to be taken, therefore, it is desirable to have the minimum period possible to attain the required sensitivity.

To obtain a high sensitivity it is important that the control be purely torsional. This is achieved in two ways. The moments of the two magnets are made as equal as possible, so that no resultant torque acts on the system. Also a compensating coil system is used to reduce the horizontal component of the earth's field.

It is desirable that the rock specimen should have no induced magnetism due to the earths magnetic field, while measurements are made of the properties of its remnant magnetism. For this purpose also a Helmholtz coil system is employed to compensate for the vertical component of the geomagnetic field. By placing the magnet system within three sets of Helmholtz coils set at right angles to each other it is possible to obtain a uniformly field free space.

No residual field gradient, due to ferro-magnetic material close to the magnet system, must be present. Thus the whole of the instrument is made of non-magnetic materials such as perspex and brass.

Construction of the Magnetometer. (~~See Plate I.~~)

The magnet system set-up is shown diagramatically in figure 22. Its housing is supported on a Muller suspension to eliminate the effects of short period vibrations.

The specimen is placed in a holder below the magnet system. It is

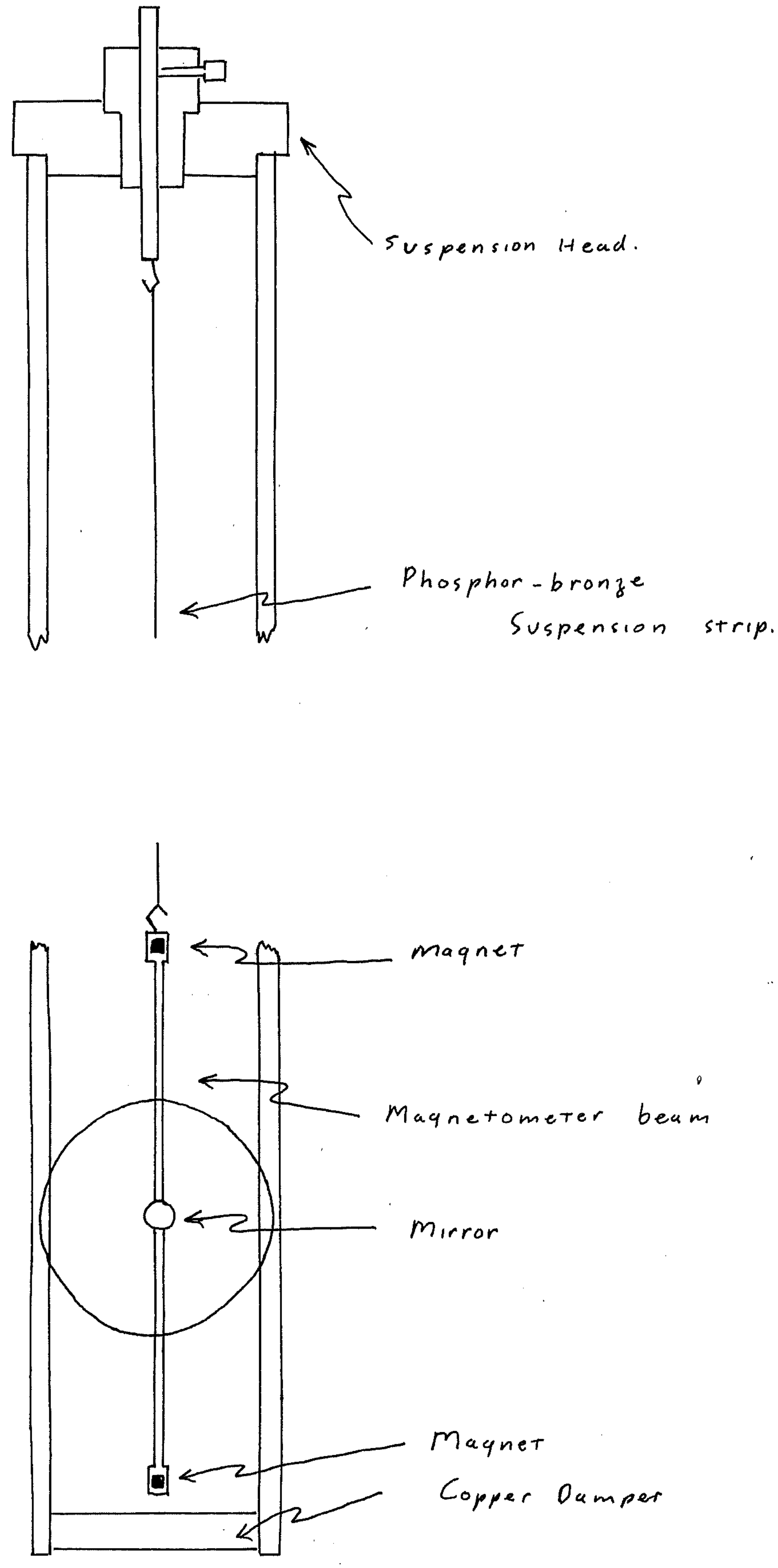

Suspension Head.
Phosphor-bronze Suspension strip.
Magnet
Magnetometer beam
Mirror
Magnet
Copper Damper

FIGURE 22.

possible to raise and lower the specimens, rotate it about a vertical axis and traverse it in an east-west direction (i.e. at right angles to the magnet system). These movements are carried out by remote control so that no disturbances are caused by approaching the instrument. The distance between the specimen and the magnet system can be accurately adjusted and a stop is provided to make it possible to repeat this distance accurately for each measurement.

The position of the specimen is determined by reading a scale on the specimen holder by means of a telescope. The deflections produced are recorded by reflection of a light beam from the mirror on the magnetic system onto a scale at the same position as the telescope.

The magnetometer has two pairs of horizontal field compensating coils, one pair with their axis aligned north-south, the other with their axis aligned east-west. The axis of the north-south field compensating coils is set slightly off azimuth and the small east-west component of the horizontal field remaining is annulled by the east-west field compensating coils. The currents passed through these two pairs of coils are 135 m.a. and 5.7 m.a. respectively.

The value of the current through the vertical pair of coils needed to compensate the vertical field is 420 m.a.

The horizontal magnetic field of the earth at Adelaide is .22 oersteds and the vertical field is .56 oersteds.

The current for the coils is supplied by lead accumulators and is adjusted by variable resistances. These together with milliammeters for reading the current through each coil are placed on the control panel shown to the left of the instrument.

The suspended system is centred within the coil system as accurately as possible and the specimen holder is also centred on the vertical axis of the magnet system.

A small coil suspended some distance above the magnet system is used to check the sensitivity of the instrument. When a certain current is passed through it, the same deflection of the magnet system should always result. The variable resistance and milliameter for this coil are placed on the control panel which is used to adjust the Helmholtz coils.

Collecting and Preparing the Specimens.

The strike direction and the dip of a surface on the rock are determined by marking three points on the surface where the 3 legs of a small triangular level come in contact with it. Two of these points are in a horizontal plane and, therefore, give the strike of the rock, while the third point shows the direction of dip. This strike and dip is recorded for use in the reduction of results.

Before coring, the specimen is set in plaster so that the surface previously measured is horizontal. Cores are removed using a non-magnetic diamond coring bit and are trimmed at both ends with a non-magnetic circular saw.

These cores are appropriately marked with a reference line so that the strike direction of the marked surface of the specimen is known for each core. All measurements with the magnetometer are therefore made relative to the strike direction of this plane.

Theory.

The specimen is regarded as a magnetic dipole and can therefore be represented by a vector in space.

This vector can be resolved into a horizontal and a vertical component and the direction and magnitude of the dipole can be found by measuring the field associated with these two components.

If the specimen is placed a distance x off the centre and rotated, the two components will have the following effects.

1. The horizontal component will have no effect when in the same direction as the magnet system. The maximum effect occurs when it is at right angles to the magnets. If the strike line on the specimen and the direction of the horizontal component do not coincide, a phase angle will be involved.
2. The vertical component (or, more exactly, the horizontal field associated with the vertical component) will affect the system at the 270^{o} and 90^{o} positions but not at the 0^{o} and 180^{o} positions regardless of phase angle.

Hence on rotation through 360^{o} both components will cause a sinusoidal variation and the actual curve obtained will be the sum of these two.

When the specimen is inverted and again rotated the effect of the vertical component is reversed.

Therefore in the upright position

Resultant = Horizontal component + Vertical Component

i.e. $R_1 = H + V$

Inverted

$$\text{Resultant } (R_2) = H - V$$

Therefore

$$R_1 + R_2 = 2H$$

$$R_1 - R_2 = 2V$$

The field due to the horizontal component is given by

$$H = VM_h \cos(\theta - D) / r^3$$

$$r^2 = z^2 + x^2$$

Therefore if x z $r \doteqdot z$

$$H = VM_h \cos(\theta - D) / z^3$$

Where

M_h = horizontal component of magnetism

θ = azimuth

D = declination of horizontal component for $\theta = 0$

Field due to the horizontal component of the vertical component

$$H^1 = \frac{VM_z \; x \; \cos\theta}{z^4} \qquad r \doteqdot z$$

In practice firstly the core is placed in the holder at a distance of 1cm. to the west of the centre of the magnet system. Readings are taken of the deflection produced on rotation at the 0°, 90°, 180° and 270° positions. The holder is then traversed to a position 1cm. to the east of the magnet system and the readings repeated. The core is then inverted and readings taken in the reverse order, i.e. in the 360°, 270°, 180° and 90° positions. These readings are also taken in both the east and west positions.

The form shown in figure 23 is used in practice.

"a" is the algebraic mean of $\frac{1}{2}(d_1 + d_5)$ etc. i.e. 0°, 180° positions
"b" " " " " " $\frac{1}{2}(d_2 + d_6)$ etc. i.e. 90°, 270° positions

Height . . . . . Traverse . . . . . Sensitivity . . . . . Date . . . . . .
Rock type . . . . Locality . . . . Spec. No. . . . . .

Upright

West		East			
0	d_1 =	0	d_5 =	$d_1 + d_5$ = ☐	$d_1 - d_5$ =
90	d_2 =	90	d_6 =	$d_2 + d_6$ =	
180	d_3 =	180	d_7 =	$-[d_3 + d_7]$ = ☐	$-[d_3 - d_7]$ =
270	d_4 =	270	d_8 =	$-[d_4 + d_8]$ =	
180	s_3 =	180	s_7 =		
0	s_1 =	0	s_5 =		

Inverted

East		West			
360	d_9 =	360	d_{13} =	$d_9 + d_{13}$ = ☐	$d_9 - d_{13}$ =
270	d_{10} =	270	d_{14} =	$d_{10} + d_{14}$ =	
180	d_{11} =	180	d_{15} =	$-[d_{11} + d_{15}]$ = ☐	$-[d_{11} - d_{15}]$ =
90	d_{12} =	90	d_{16} =	$-[d_{12} + d_{16}]$ =	
180	s_{11} =	180	s_{15} =		
0	s_9 =	0	s_{13} =		

$s_3 - d_3$ =
$s_1 - d_1$ =
$s_7 - d_7$ =
$s_5 - d_5$ =
$s_{11} - d_{11}$ =
$s_9 - d_9$ =
$s_{15} - d_{15}$ =
$s_{13} - d_{13}$ =

$\overline{}$ / 8

Susceptibility

$= \frac{kz}{3x} \cdot \frac{1}{\cdot 56 \text{ vol}}$

= ________

$a = \frac{☐}{8}$

$b = \frac{}{8}$

$\tan\alpha$ =

$\therefore \alpha$ =

Declination = ________

$d_h = \sqrt{a^2 + b^2}$

$= \sqrt{}$

$P_h = k$

= ________

$d_u = \frac{}{8}$

$P_z = \frac{kz}{3x}$

= k

= ________

$\tan\phi = \frac{P_z}{P_h}$

$\therefore \phi$ =

$P_t = k\sqrt{d_h^2 + d_u^2[z/3x]^2}$

____

FIGURE 23.

~~Fig.5.~~

The above procedure averages out non-uniformities of magnetization in specimens.

Field due to horizontal and vertical components of dipole.

The magnetic field of the horizontal component of the dipole, P_H, has components. (Fig 24)

$$Hr = \frac{2P_H \cos\theta}{r^3}$$

$$H_\theta = \frac{P_H \sin\theta}{r^3}$$ If $\theta \rightarrow 90^o$ this is the larger.

Field due to horizontal component.

$$= H_\theta \sin\theta - Hr \cos\theta$$

$$= - \frac{2 P_H \cos\theta . \cos\theta}{r^3} + \frac{P_H}{r^3} \text{Sin}\, \theta . \sin\theta$$

$$= \frac{P_H}{r^3} (-2 \cos^2\theta + \sin^2\theta)$$

But $\text{Sin}\,\theta = \frac{z}{r}$ so that the horizontal field

$$= \frac{P_H}{z^3} (\sin^2\theta - 2\cos^2\theta) \sin^3\theta$$

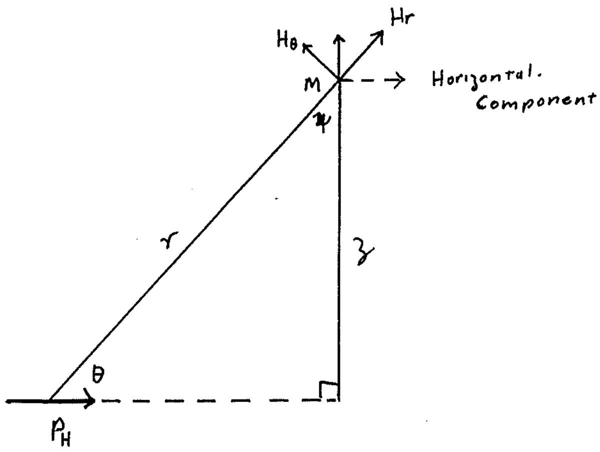
$$= \frac{P_H}{z^3} \{ \sin^2 (90 - \psi) - 2 \cos^2 (90 - \psi) \} \sin^3 (90 - \psi)$$

$$= \frac{P_H}{z^3} (\cos^2\psi - 2 \sin^2\psi) \cos^3\psi$$

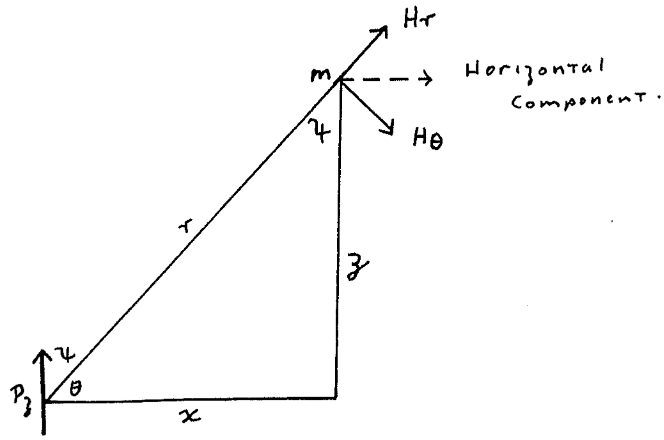
Field due to vertical component has components

$$Hr = \frac{2 P_z \cos\psi}{r^3}$$

$$H = \frac{P_z \sin\psi}{r^3}$$



Hr
Hθ
M
Horizontal.
Component
ψ
r
z
θ
P_H



Hr
m
Horizontal
Component.
Hθ
ψ
r
z
ψ
θ
P_z
x

FIGURE 24

The horizontal component in this case

$$= Hr \sin\psi + H \cos\psi$$

$$= \frac{2Pz}{r^3} \cos\psi \sin\psi + \frac{Pz}{r^3} \sin\psi \cos\psi$$

$$= \frac{Pz}{r^3} (2 \cos\psi \sin\psi + \cos\psi \sin\psi)$$

$$= \frac{3Pz}{r^3} (\cos\psi \sin\psi)$$

Therefore Field $= \frac{3Pz}{r^3} \cos^4\psi \sin\psi = \frac{3Pz}{z^4} \cos^4\psi$

Therefore $P_H = \frac{H_H \quad z^3}{(1 - 3 \sin^2\psi) \cos^3\psi}$

$$Pz = \frac{Hz \cdot z^3}{3 \cos^4\psi \sin\psi}$$

<u>Total Moment of Magnetization.</u>

A field of 7×10^{-7} oersted at the bottom magnet produces 1mm. deflection on the scale.

Horizontal field at bottom magnet is due to the horizontal component of the dipole $= \frac{P_H}{z^3}$ at distance z (1)

Horizontal field at bottom magnet due to the vertical component

$$= \frac{3x\ Pz}{z^4} \qquad (2)$$

If specimen is traversed a distance x off centre.

Deflection due to (1) $= d_H$ cms. (2) $= d_z$ cms.

Therefore field $= d_H.(7 \times 10^{-6})$ oersteds

Therefore $P_H = d_H \{z^3 \times 7 \times 10^{-6}\}$

$$= Kd_H \qquad \text{where } K = 7 \times 10^{-6} \,.\, z^3$$

$$Pz = dz \left\{ \frac{z}{3x} \right\} K \qquad \text{where } K = 7 \times 10^{-6} \,.\, z^3$$

Total Moment

$$= \quad P_H^{\,2} + Pz^2$$

$$= K \left\{ d_H^{\,2} + dz^2 \left(\frac{z}{3x} \right)^2 \right\}$$

$$= K \quad a^2 + b^2 + dz^2 \left(\frac{z}{3x} \right)^2 \qquad\qquad a^2 + b^2 = d_H^{\,2}$$

Tan Ø (where Ø = inclination)

$$= \frac{Pz}{P_H}$$

$$= \frac{dz}{dh} \cdot \frac{z}{3x}$$

$$= \frac{b}{a} \cdot \frac{z}{3x}$$

Susceptibility.

The magnetism induced by the earth's field is found by switching off the vertical Helmholtz coils and noting the changes in deflection in the 90^{o} and 270^{o} positions.

The inducing field will, of course, be the vertical component of the earth's field.

Suppose the differences in readings for vertical field on and off = ds.

This will be the deflection due to a vertical dipole Ps at a distance x off the axis.

$$\text{field} = \frac{3x\ Ps}{z^4} = ds \quad (7 \times 10^{-6})$$

$$\text{therefore}\quad Ps = ds\ (7 \times 10^{-6})\ z^3 \quad \frac{z}{3x}$$

$$= K\ ds\ \frac{z}{3x} \qquad K = 7 \times 10^{-6} \cdot z^3$$

$$I = \text{moment/unit vol.} = \frac{Ps}{Vol} = kH$$

$$\text{therefore}\quad k = \frac{Ps}{Vol \times (\cdot 56)}$$

Vertical component of earth's field at Adelaide is ·56 oersteds

APPENDIX II.

MAGNETIC CALCULATIONS

The method of calculation of the theoretical anomalies and the various methods of depth determination are given; and their applicability to the type of anomaly considered in this paper are discussed.

By their very nature, potential fields are ambiguous. In most cases, several different sub-surface configurations could all give rise to the same anomaly.

Formulas usually express the magnetic intensity over a body as a function of the dimensions, positions, and susceptibility of the body; and the strength and direction of the earth's magnetic field.

For any area the properties of the earth's field are usually known, so that if, by some means, one or two of the variables for a body is known a unique solution for a particular anomaly can often be derived.

Assumptions

All methods for the theoretical analysis of an anomaly depend on the following assumptions.

(1) The anomalous field is small compared with the normal total intensity of the earth's field. In this case, the component of intensity in the direction of the total field can be considered to be the same as the component in the direction of the earth's field.

(2) The body is uniformly magnetized throughout its whole extent.

(3) Demagnetization effects produced by the existance of the body in the earth's field are ignored.

(4) The polarization of the magnetized body is in the direction of the earth's field. For those cases where the rocks possess a permanent remnant magnetism which is constant in some direction, other than that of the earth's field, the total magnetization vector (i.e. the vector sum of the remnant and induced magnetizations) may differ greatly in direction from the present earth's field.

<u>Calculation of anomalies</u>

The method used in calculating all the theoretical anomalies is that given by Cooke (1950).

The formulas given apply only to two-dimensional bodies, whose length in the direction of strike is infinite. Consideration is given to only those veins where the depth extent is greater than the width.

The general formula given is:

$$Z = 2 k Zo \sin\delta \left\{ (Ho \sin\alpha \sin\delta + Zo \cos\delta) \log_e \frac{r_2 r_3}{r_1 r_4} - (Ho \sin\alpha \cos\delta - Zo \sin\delta)(\phi_1 - \phi_2 - \phi_3 + \phi_4) \right\}$$

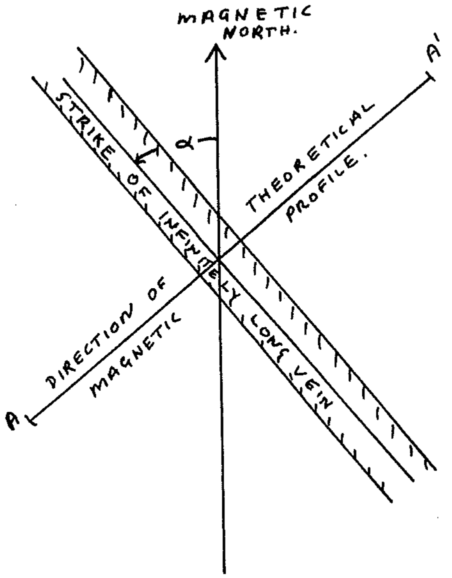
For the definition of ϕ, r, α and δ, reference should be made to figure ~~24~~ 25.

Ho and Zo are respectively the horizontal and vertical components of the earth's magnetic field in the area considered.

k is the difference in susceptibility between the magnetic body and the surrounding rocks.

DIAGRAMMATIC

PLAN



VERTICAL SECTION.

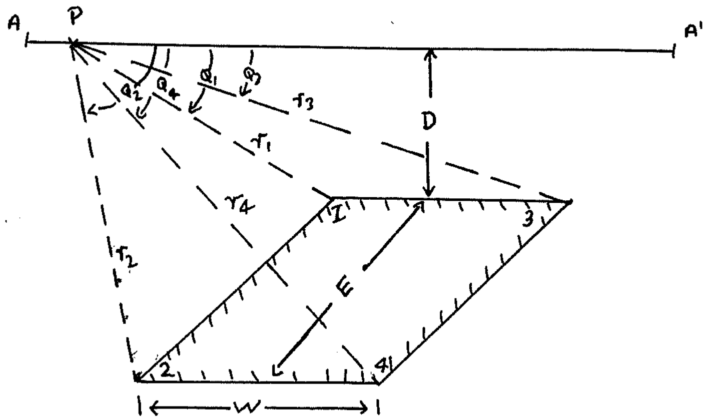


FIGURE 25.

Considering the Nairne Pyrite Formation the following simplifications can be made.

(a) Only the vertical intensity is measured, therefore $Ho = 0$

(b) The strike of the body is north-south, therefore $\alpha = 0$

(c) The body is infinitely deep, therefore, it can be assumed that

$$r_2 = r_4$$

and

$$\varnothing_2 = \varnothing_4$$

Therefore, for an infinite inclined vein striking north, the formula can be reduced to

$$Z = 2k\ Zo \sin \delta \left\{ \cos \delta \log_e \frac{r_3}{r_1} + \sin \delta (\varnothing_1 - \varnothing_3) \right\}$$

and for an infinite vertical vein striking north

$$\delta = 90^o$$

therefore, $\sin \delta = 1$

$$\cos \delta = 0$$

and

$$Z = 2k\ Zo\ (\varnothing_1 - \varnothing_3)$$

These were the formulas used in the theoretical calculations.

An error will be introduced when calculating the theoretical bodies derived for the ground magnetic traverses due to the shallowness of the bodies in comparison with their width. This would be negligable in the case of profile z-z', but could produce an error in the theoretical curve derived for profile x-x'.

In the calculation of the theoretical bodies for the aeromagnetic anomalies the horizontal component of the earth's field has been ignored. Because of the high geomagnetic latitude at which the horizon occurs the error arising here would be small.

The method given by Peters (1949) was also tried. The formula given is

$$Hz = 2\Delta I_3 \left\{ \tan^{-1} \frac{x + m}{h} - \tan^{-1} \frac{x - m}{h} \right\}$$

$$+ \Delta Ix \log_e \frac{(x + m)^2 + h^2}{(x - m)^2 - h^2} + \text{CONST.}$$

(See Fig. 26).

As Cooke's method is the simplest for vertical force anomalies, Peter's formula was only tried on aeromagnetic maps.

The formula, however, is very insensitive to changes in height when $\frac{m}{h}$ is less than .5. The best results are obtained when $\frac{m}{h}$ is greater than 1.1.

In the case of the Nairne pyrite horizon the width of the body is small, even in those cases where the anomaly is complex. Therefore, the fraction $\frac{m}{h}$ is always equal to or less than $\frac{1}{2}$, and calculations using this method do not give good results.

<u>$\frac{1}{2}$ width method of depth estimation.</u>

The distance from the point where the anomaly has its maximum

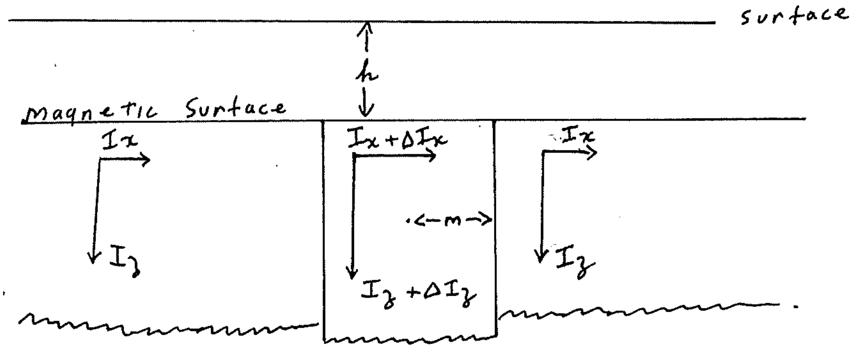


FIGURE 26

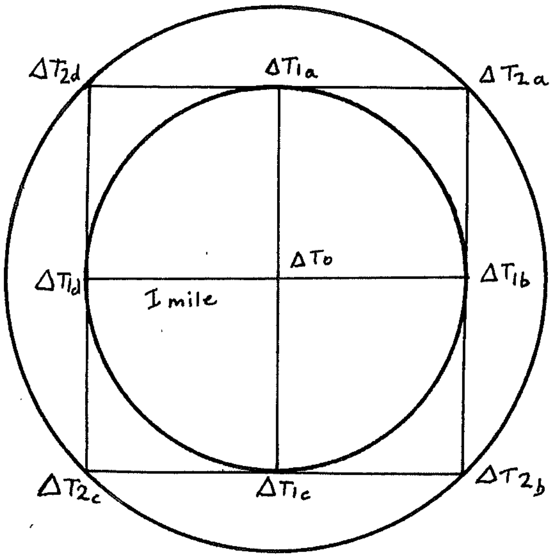


FIGURE 27.

value, to the point where the value is equal to half this maximum is measured. In high magnetic latitudes this distance is equal to the depth to the top of the body producing the anomaly. A good estimation of the depth is theoretically possible for the Nairne Pyrite Horizon.

In this case, the method has two weaknesses.

(1) The body is dipping to the east. The two $\frac{1}{2}$-width distances will consequently be different and only a range of depth values can be obtained.

(2) It is difficult to obtain the value of the anomaly remote from the horizon, due to the presence of other anomalies, and, therefore, it is not always possible to determine the half maximum value with adequate precision.

Smellie's Method

Smellie (1956) gives a method of depth estimation which is an elaboration of that given by Henderson and Zeitz (1948). Four cases are considered in which the source of the anomaly is approximated to a point pole, line of poles, point dipole, and line of dipoles respectively.

In each case, factors are calculated which, when multiplied into the distance from the maximum to half-maximum along the profile, yield the depth to the source.

Also, the ratio of half maximum distances (n:n') for theoretical bodies have been plotted for various values of the strike of the body and the angle of inclination of the earth's field. By comparing the ratio actually obtained with the theoretical ratio, some idea of the actual dimensions of the body, can be obtained.

In the case of the Nairne Pyrite Formation a line of poles was found to be the best approximation.

For complex sources (e.g. profile A-A'), the estimated depth will be a maximum value, useful at least for distinguishing deep from shallow seated sources.

Sutton and Mumme (1956) have considered the effect that remnant magnetism may have on the anomalies produced by the four theoretical sources.

In the case of the pyrite formation, the various components of the remnant magnetism have been assumed to annul each other at the flight height.

<u>Peter's Slope Method.</u>

Briefly the method of calculation is:

draw the maximum slope at the point of inflection; draw a line whose slope is half this maximum slope; draw two lines parallel to this line, tanjent to the anomaly curve.

The horizontal distance D between the points of tanjency is approximately equal to 1.6h. Actually when $\frac{m}{h} = 0$, $D = 1.2h$ and when $\frac{m}{h} =$, $D = 2.0h$.

Calculations of this type were not carried out on anomalies in this case because of:-

(1) Assymetry of the profiles

(2) Difficulty in picking point of maximum slope

(3) Difficulty in picking the correct inflection points.

Because of its more symmetrical nature, this method was tried on profile E-E'. Here, the body is relatively thin compared with its distance below the flight line and so the formula $D = 1.4h$ was used. A good correspondence with other methods was obtained.

Vaquier et al.

Vaquier et al. (1951) have used vertical prismatic models for the interpretation of aeromagnetic anomalies. Estimations of the depths and size of a body are made by comparing the anomaly with one of those produced by various shaped models at different inclinations of the earth's field.

Although results obtained on the anomalies produced by the pyrite horizon agreed with other methods, this method appears to be more applicable to larger and more deep seated anomalies.

Second derivitive maps.

The formula used was that given by Henderson and Zeitz (1949) namely,

$$\frac{\partial^2 \Delta T}{\partial z^2} = 2\{3\Delta To - 4\Delta T_1 + \Delta T_2\}$$

where $\frac{\partial^2 \Delta T}{\partial z^2}$ = value of second derivitive

ΔTo = value of magnetic intensity at point at which the second derivitive is being calculated.

ΔT_1 = average value of magnetic intensity around a circle of radius 1 unit and with centre To.

ΔT_2 = average value of magnetic intensity around a circle of radius $\sqrt{2}$ units with centre Δ To.

Unit radius was taken as 1 mile and points were plotted on a half-mile grid.

Actually, the average of four points at the corners of a 1 mile square grid were assumed to be adequate to represent the average of Δ T on each circle. (See fig. 27.).

A fair degree of control is provided by the fact that the flight lines are perpendicular to the strike of the body. However, if the strike of the body as well as the flight lines was east-west, no recognizable anomaly would be obtained if the horizon fell about half-way between two of the flight lines.

Therefore, although the 1 mile spacing is adequate in this case, a line-spacing of as little as $\frac{1}{4}$ mile would usually be needed to provide a small enough grid to delineate a body as shallow as this.

APPENDIX III.

LIST OF SPECIMENS AND RESULTS

Core No.	Declin.	Inclin.	Total Remnant Magnetism	Suscept.	Location
1a	254^{o}	60^{o}	$6.79.10^{-4}$	$1.09.10^{-3}$	No. I face
1b	250^{o}	62^{o}	$5.30.10^{-4}$	$1.09.10^{-3}$	"
3a	276^{o}	-35^{o}	$1.9.10^{-7}$	——	Schist below N.P.F.
6a	352^{o}	42^{o}	$7.42.10^{-4}$	$9.2.10^{-4}$	No. 3 face
6b	356^{o}	40^{o}	$6.70.10^{-4}$	$1.14.10^{-3}$	"
8a	341^{o}	55^{o}	$2.29.10^{-4}$	$6.34.10^{-4}$	"
8b	340^{o}	60^{o}	$2.54.10^{-4}$	$5.86.10^{-4}$	"
9a	---	--	---	---	In adit (20' from mouth)
10a	332^{o}	20^{o}	$2.84.10^{-4}$	$7.26.10^{-4}$	Adit (73' from mouth)
10b	330^{o}	18^{o}	$2.74.10^{-4}$	$6.94.10^{-4}$	"
11a	150^{o}	-40^{o}	$1.08.10^{-3}$	$2.53.10^{-3}$	Adit (122' from mouth)
11b	155^{o}	-67^{o}	$6.74.10^{-4}$	$1.53.10^{-3}$	"
12a	136^{o}	80^{o}	$2.47.10^{-4}$	$1.11.10^{-3}$	Adit (273' from mouth)
12b	222^{o}	83^{o}	$3.50.10^{-4}$	$1.23.10^{-3}$	"
14a	250^{o}	-18^{o}	$7.2.10^{-6}$	$4.81.10^{-6}$	No. 3 face
14b	247^{o}	-14^{o}	$1.31.10^{-5}$	$2.11.10^{-6}$	"
15a	223^{o}	-8^{o}	$3.27.10^{-6}$	$5.22.10^{-6}$	"
15b	238^{o}	-12^{o}	$3.31.10^{-6}$	$2.11.10^{-6}$	"
16a	354^{o}	41^{o}	$6.41.10^{-4}$	$1.18.10^{-3}$	"
16b	351^{o}	46^{o}	$6.0.10^{-4}$	$7.26.10^{-4}$	"
17a	146^{o}	74^{o}	$1.44.10^{-3}$	$1.56.10^{-3}$	"
17b	272^{o}	88^{o}	$1.28.10^{-3}$	$2.84.10^{-3}$	"
18a	341^{o}	72^{o}	$1.03.10^{-3}$	$1.23.10^{-3}$	"
18b	345^{o}	66^{o}	$1.15.10^{-3}$	$1.94.10^{-3}$	"
20a	343^{o}	65^{o}	$1.77.10^{-3}$	$1.81.10^{-3}$	"
20b	325^{o}	70^{o}	$1.76.10^{-3}$	$1.86.10^{-3}$	"
21a	170^{o}	82^{o}	$6.90.10^{-4}$	$1.75.10^{-3}$	"
21b	312^{o}	77^{o}	$6.92.10^{-4}$	$9.25.10^{-4}$	"

Core No.	Declin.	Inclin.	Total Remnant Magnetism	Suscept.	Location
22a	319^o	51^o	$1.17.10^{-3}$	$9.91.10^{-4}$	No. 3 face
22b	323^o	55^o	$1.12.10^{-3}$	$7.6.10^{-4}$	"
23a	266^o	80^o	$6.0.10^{-4}$	$5.33.10^{-4}$	"
23b	317^o	68^o	$5.91.10^{-4}$	$5.68.10^{-4}$	"
24a	10^o	4^o	$8.84.10^{-5}$	---	"
24b	15^o	15^o	$3.86.10^{-5}$	---	"
25a	28^o	72^o	$3.18.10^{-4}$	---	"
25b	9^o	70^o	$4.48.10^{-4}$	---	"
12b (repeat)	305^o	72^o	---	---	---------
H1a	---	--	$1.1.10^{-5}$	---	Arkose - 2 miles north of Harrogate
H1b	---	--	$5.3.10^{-5}$	---	"
H1c	---	--	$9.2.10^{-6}$	$1.99.10^{-5}$	"